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Category:	Design/Construction of Fixed Bottom Turbines
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Subject:	*Safety of Renewable Energy Operation in the U.S. Outer Continental Shelf*
Performing Activity:	BMT Fleet Technology
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Contracting Agency:	Bureau of Safety and Environmental Enforcement
Summary:	The objective of this project was to evaluate fatigue design methodologies and design criteria on offshore wind turbine support structures that make use of the Miner-Palmgren cumulative damage hypothesis and fracture mechanics, including the characterization of ice loads for fatigue.
Key Findings:	• The relevant standards and guidelines are based on established principles of design, defining a comprehensive methodology for estimating and achieving the desired service life for fatigue. The design philosophies and the approaches taken (mainly, the limit states design approach) provide a consistent method by which a safe, reliable structural design can be achieved. • Certification is based largely on monopile installations or other fixed-type installations. • For the fatigue limit state, all partial load factors are uniformly defined in the existing standards and guidelines (equal to 1.0); however, partial resistance factors diverge. • With respect to the fatigue design of OWTG tower support structures, a safe life philosophy is applied. The development of the partial resistance factors and the limit states design approach are consistent with safe life, based on a prescribed service life for design. Components may be designed as damage tolerant, where appropriate, using fracture mechanics and a defined inspection program. For the tower structures (and monopiles, a fail-safe approach is limited since the towers are not redundant structures. • Some standards and guidance documents (DNV-OS-J101 and GL) apply material S-N curves, which have been determined only from tests using base materials. This approach is not conservative, and stress concentration factors must be applied subsequently to account for the effects of weld residual stresses. Therefore, when applying an S-N curve for design, it is important to understand the basis from which the characteristic curve has been derived. • In addition to the different factors affecting the classification of design S-N curves, the calculated stress ranges may need to be adjusted to reflect the effects on the number of cycles with consideration of material thickness (or size) effects, mean stress effects, and the effects of any surface treatments applied.

	• The fatigue performance of an OWTG tower structure can be improved over the service life by employing good design practice, including selecting the appropriate details for design (considering plate thickness, stress concentrations, weld details, etc.) and by specifying the appropriate fabrication procedures (i.e., post-welding treatments, like grinding). A comprehensive inspection and maintenance program is required to ensure performance for the service life.
Recommendations:	• The operation of the wind turbine creates significant aerodynamic load effects that must be considered and may-require aero elastic analyses. • A dynamic analysis is necessary to ensure that the natural frequency of the OWTG support structure does not approach the excitation frequency and its higher harmonics of functional loads or the frequency of energy-rich environmental loads. • The modeling of welds, specifically at the weld toe regions as relevant to the evaluation of hot-spot stress ranges, requires special consideration. Guidance is provided in DNV-RP-C203 regarding the modeling and analysis by finite element methods of the stress distributions local at hot-spot regions. • The response of the structure is most effectively considered using a fully coupled, integrated approach (which considers the aerodynamic and structural damping). • For fixed-type structures, consideration of the elastic behavior of the support structure is required. The behavior of the support structure and the natural frequencies will be influenced by the elastic foundation stiffness. The transient behavior of the soil-stiffness interaction for the life of the structure may be an important design consideration. Changes in the soil stiffness over time may affect the resonant frequencies of fixed structures. • The structural analysis of an OWTG is a complex endeavor and may be completed in the frequency domain. However, a structural analysis in the time domain directly calculates the effects of fatigue loading and, considering recent advances in software and computing power, is the preferred approach. <u>Ice Effects on Fatigue</u> • The use of existing standards and guidelines, including IEC 61400, DNV-OS-J101, and ISO 19906, is the preferred approach for the characterization of ice loads for fatigue. • ISO is more precise than IEC and DNV, but it may not be more accurate. • Rafted ice events produced larger load reversals, even though there were fewer cycles. The sheet ice events produced lower load reversals with a larger number of cycles.

	• The resulting S-N curve from IEC 61400 spanned a wide range due to the inclusion of both rafted ice and sheet ice. DNV-OS-J101 also indicated that the number of cycles was inversely related to the magnitude of the load reversal. • The S-N curve for DNV-OS-J101 spanned a narrower range of load reversal magnitudes than did the one from IEC 61400. This is due to the fact that only certain cases for sheet ice needed to be included for DNV-OS-J101. The variation is mainly due to differences with respect to rafted ice; these cases generated the highest ice loads and largest load reversals. Furthermore, DNV-OS-J101 indicated that significantly lower load reversal magnitudes were associated with a given number of cycles than in IEC 61400. Again, this variation is principally due to the fact that the rafted ice cases did not meet the tuning criterion in DNV-OS-J101; thus, they were excluded. • The results demonstrated the significance of differences between the methodologies prescribed in IEC 61400 and DNV-OS-J101.
Subsequent Studies/Activities:	• FY 2014 study award: Fatigue Design Methodologies Applicable to Complex Fixed and Floating OWT • FY 2014 project award: Design of Wind Turbine Monopiles for Lateral Loads
Report Link:	AA: "Fatigue Design Review of Offshore Wind Turbine Generator Structures - Final Report" (Ref: 30087.FR)